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Workshop On Fire Testing Measurement Needs: Proceedings

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(Editor)

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F. MEASUREMENT UNCERTAINTIES INS STANDARD FIRE TESTS

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Measurement of Uncertainties

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Motivation

- **ISO 17025 -** December **31,2002**

  Test laboratories must have and apply procedures for estimating uncertainty of measurements.
- **ISO 5725 -** Guide to the Expression **of** Uncertainty in Measurement (GUM)

What is Uncertainty?

- Doubt that exists about the result of any measurement at any level, *i.e.* national laboratories, test laboratories, calibration laboratories, and end users.
- Tolerances are **not** uncertainties, but are acceptance limits.
- Specifications are **not** uncertainties. Specifications tell you what you can expect for a group or type of **instruments.**

Approach to Meet Requirements

- Calculate measurement uncertainty in accordance with **ISO 5725**
- Support all measurements with uncertainty budgets
- Represent as expanded uncertainties using a coverage factor of **2** to approximate the 95% confidence level

Reporting a Measurement

- "M" = 0.00 ± 0.00 (95% Confidence Level)
- "M" = 0.00 ± 0.00, 95% C.L.
- "M" = 0.00 measured with an uncertainty off 0.00 with a coverage factor **of** 2

Uncertainty Evaluation

- Type A Evaluation
  - Based on statistical analysis of a series of discrete observations using
    - **Sample mean -** $(\bar{x}) = \left(\frac{1}{N}\right)\sum x_i$
    - **Sample variance -** $\sigma^2 = \left(\frac{1}{N-1}\right)\sum (x_i - \bar{x})^2$
  - Usually at a 95% Confidence Level

Uncertainty Evaluation

- Type B Evaluation
  - When the information is scarce, it is based on scientific judgment using all relevant information available.
    - Previous measurement data
    - Experience with the behavior and property of relevant materials and instruments
    - Manufacturer's stated specifications
    - Engineering evaluation
    - Data provided in calibration and other reports
    - Uncertainties assigned to reference data taken from handbooks

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Combined Type A, B Evaluation

$$u_t = \sqrt{\left\{\left(\frac{\delta E}{\delta x_1}\right) \times u_1\right\}^2 + \ldots + \left\{\left(\frac{\delta E}{\delta x_n}\right) \times u_n\right\}^2}$$

u_t = total measurement uncertainty

$\delta E/\delta x_i$ = partial derivative of the defining test equation with respect to the i^{th} individual measurement

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Concerns

- Test labs very seldom have enough data to make a Type A estimate, resulting in uncertainty of Type B only.
- Manufacturers of instruments do not always provide complete uncertainty statements
- Calibration laboratories should be foilowing ISO **17025,** but this is an ongoing process and many are not fully up to speed (calibration laboratories may require more than **2** years to comply ISO **17025)**

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Concerns

- Some test equipment is unique and has no means of outside calibration. Must rely on calibration of components and subsystems.
- Equipment may have embedded sensors or transducers that cannot be removed and reinstalled without destruction.
- There is a shortage of accredited callbration laboratories to meet the demand of the test laboratories.
  - Results in higher cost
  - Time delays

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Concerns

- For each increment of accuracy, cost increases proportionally.
- Tolerances are often used as uncertainties because manufacturers rarely provide uncertainty data.
- if routine recalibration shows an instrument to be out of specification, it casts doubt on ALL test results generated with the instrument since its last calibration
- interlaboratory proficiency testing (round robin) is an option, but it has associated cost to the laboratories.

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Type B Evaluation for HRR Measurement - ASTM E 1354

- Evaluation for uncertainty in HRR requires measurement of
  - Differential pressure, ΔP
  - Exhaust duct temperature, T_e
  - Mole fraction of oxygen, X_{O_2}
- The instruments used to make these measurements rely on the following manufacturer specifications
  - Pressure transducer - 1%
  - Thermocouple - 0.75%
  - Oxygen analyzer - 0.5%

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HRR **Example**

- Uncertainty calculation assumes a rectangular distribution found from $a/\sqrt{3}$ where a is the upper and lower range of the limit
- Expanded uncertainty uses root sum square method with coverage (k) factor of 2 for 95% confidence level

$$u_t = \left\{ \sqrt{\left(\frac{u_{\Delta P}}{\sqrt{3}}\right)^2 + \left(\frac{u_{T_e}}{\sqrt{3}}\right)^2 + \left(\frac{u_{X_{O_2}}}{\sqrt{3}}\right)^2} \right\}\%$$

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HRR **Example**

$$u_t = \left\{ \sqrt{\left(\frac{1.00}{\sqrt{3}}\right)^2 + \left(\frac{0.75}{\sqrt{3}}\right)^2 + \left(\frac{0.50}{\sqrt{3}}\right)^2} \right\}\% = 0.78\%$$

- Coverage (k) factor of 2

$$u_t = 2 \times 0.78\% = 1.56\%$$

- Provides 95% confidence level

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HRR **Example**

- HRR = $f(\Delta P, T_e, X_{O_2}, \Delta h_c/r_0)$ where
- $\Delta h_c/r_0$ = 13.1 x 10^3 kJ/kg oxygen
  - Δh_c = net heat of combustion
  - r_0 = stoichiometric oxygen/fuel mass ratio
  - $\Delta h_c/r_0$ = oxygen consumption standard value
- ASTM **E 1354** gives an associated error for $\Delta h_c/r_0$ of 5%
- Therefore, the error in $\Delta h_c/r_0$ must be Incorporated into the root sum square equation

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HRR **Example**

$$u_t = \left\{ \sqrt{\left(\frac{u_{\Delta P}}{\sqrt{3}}\right)^2 + \left(\frac{u_{T_e}}{\sqrt{3}}\right)^2 + \left(\frac{u_{X_{O_2}}}{\sqrt{3}}\right)^2 + \left(\frac{u_{\Delta h_c/r_0}}{\sqrt{3}}\right)^2} \right\}\%$$

$$u_t = \left\{ \sqrt{\left(\frac{1.00}{\sqrt{3}}\right)^2 + \left(\frac{0.75}{\sqrt{3}}\right)^2 + \left(\frac{0.50}{\sqrt{3}}\right)^2 + \left(\frac{5.00}{\sqrt{3}}\right)^2} \right\}\%$$

$$u_t = 2.99\% \sim 3\%$$

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HRR **Example**

- Approximated "standard deviation"

$$u_t = 3\%$$

- Coverage (k) factor of 2 = expanded uncertainty

$$u_t = 2 \times 3\% = 6\%$$

- Provides for 95% confidence level

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Summary

- Uncertainty budget necessary to identify major contributing factors
- Uncertainty budget shows the overriding uncertainty comes from the oxygen consumption standard value
- Why pursue greater tolerances in pressure transducers, thermocouples, *etc.*, when largest contributing factor is inherent in the oxygen consumption standard value?

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